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Title Forage value in leaf and stem biomass fractions of selected grasses indigenous to African drylands

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Abstract

In African drylands, indigenous grasses such as Eragrostis superba Peyr, Enteropogon macrostachyus Munro ex Benth., and Cenchrus ciliaris L. constitute a major portion of the basal diet for free ranging livestock herds. Studies to establish biomass allocation to leaf and stem fractions and determine the chemical components of these portions are absent. Lack of such information has hampered selection, development and promotion of indigenous grasses for improved livestock production in African drylands. The objectives of this study were to determine and compare: (1) allocation of biomass and (2) chemical and mineral components in the leaf and stem biomass fractions of the three selected grasses indigenous to African drylands. Chemical and mineral components were determined from biomass harvested at an early vegetative phase. Briefly, dry matter (DM) was estimated by oven drying at 60 °C for 24 h. Ash content was determined by manually combusting biomass in a muffle furnace at 650 °C for 24 h. Organic matter (OM) content was calculated as the difference between dry matter and ash content. Nitrogen content was determined by the Kjeldahl method and used to estimate crude protein (CP). Neutral Detergent Fibre (NDF) was assayed without heat stable amylase and expressed inclusive of residual ash. Acid Detergent Fibre (ADF) was expressed inclusive of residual ash. Acid Detergent Lignin (ADL) was determined by solubilisation of cellulose with sulphuric acid. Wet ash method was used to prepare samples to determine Ca (Atomic Absorption Spectrometry (AAS)), P (UV-Visible Spectroscopy) and K (Flame Emission Spectroscopy (FES)) contents. Leaf and stem biomass fractions varied significantly between the forage grasses. Leaf-to-stem ratio of E. superba was two times more compared to E. macrostachyus and C. ciliaris. Estimates of chemical components and derived estimates of energy values ADF, digestible dry matter (DDM), total digestible nutrients (TDN), metabolic energy (ME) and net energy of lactation (NEl), maintenance (NEm) and gain (NEg) were significantly higher ($P > 0.05$) in leaf compared to stem biomass in all the grass species. Mineral content also varied between the leaf and biomass fractions with E. superba having significantly higher Ca content in leaf biomass fraction. Our results strongly suggest that E. superba is a more superior forage species compared to E. macrostachyus and C. ciliaris. In conclusion, E. superba demonstrated high potential for ruminant animal production. Therefore, considering its superior nutritive quality, wide ecological range and adaptability to harsh climate, E. superba should be promoted for inclusion in pasture establishment programs in African dryland environments.

Keywords tropical grasses; biomass fractions; Eragrostis superba; Enteropogon macrostachyus; Cenchrus ciliaris

Taxonomy Agriculture, Animal Science

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To
The Editor-in-Chief
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RE: Manuscript Submission - Forage value in leaf and stem biomass fractions of selected grasses indigenous to African drylands

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We hereby submit our manuscript entitled 'Forage value in leaf and stem biomass fractions of selected grasses indigenous to African drylands' for your favourable publication consideration in the '**Animal Feed Science and Technology Journal**'

Pastoral livestock production remains a key source of livelihood of many inhabitants of African drylands. Indigenous forage grass species adapted to the harsh dryland environment provide the main source of feed for the free ranging livestock herds. Despite their significance, few studies have been conducted to establish their nutrient content. Furthermore, the contribution of the leaf and stem biomass fractions to the nutritional quality of this grasses is largely unknown. This study attempted to fill this gap by separating leaf and stem biomass fractions of three (3) important forage grass species: *Eragrostis superba* (Maasai Love Grass)*, Enteropogon macrostachyus* (Bush Rye Grass) and *Cenchrus ciliaris* (African Foxtail Grass), indigenous to Africa. Our results show that the species allocate biomass to the leaf and stem fractions differently. Additionally, the forage quality indicators varied between the species but were generally much higher in leaf compared to stem biomass fractions. The findings in this study demonstrate *E. superba* to be a more superior grass forage compared to *E. macrostachyus* and *C. ciliaris*. Considering its forage value, adaptation to harsh dryland climate and wide ecological range, *E. superba* should be promoted and included in reseeding and pasture establishment programs in African drylands.

The research topic and outcomes fit well within the scope of the journal. Therefore, we believe that the results reported will be of great interest to a wider audience in the fields of Animal Feed Science and Production. Financial support for this research project was provided by the NWO-WOTRO Netherlands Organisation for Scientific Research and Science for Global Development under the Food and Business Applied Research Fund (ARF), 2016.

The authors have all contributed to the manuscript and declare no conflict of interest. We look forward to a favourable review process.

Yours sincerely,

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Highlights

- Biomass allocation in leaf and stem fractions differed between grass species
- *Eragrostis superba* two times higher leaf-to-stem ratio
- High forage value in leaf compared to stem biomass fractions
- *Eragrostis superba* superior forage species

Forage value in leaf and stem biomass fractions of selected grasses indigenous to African drylands

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Abstract

In African drylands, indigenous grasses such as *Eragrostis superba* Peyr, *Enteropogon macrostachyus* Munro ex Benth., and *Cenchrus ciliaris* L. constitute a major portion of the basal diet for free ranging livestock herds. Studies to establish biomass allocation to leaf and stem fractions and determine the chemical components of these portions are absent. Lack of such information has hampered selection, development and promotion of indigenous grasses for improved livestock production in African drylands. The objectives of this study were to determine and compare: (1) allocation of biomass and (2) chemical and mineral components in the leaf and stem biomass fractions of the three selected grasses indigenous to African drylands. Chemical and mineral components were determined from biomass harvested at an early vegetative phase. Briefly, dry matter (DM) was estimated by oven drying at 60 °C for 24 h. Ash content was determined by manually combusting biomass in a muffle furnace at 650 °C for 24 h. Organic matter (OM) content was calculated as the difference between dry matter and ash content. Nitrogen content was determined by the Kjeldahl method and used to estimate crude protein (CP). Neutral Detergent Fibre (NDF) was assayed without heat stable amylase and expressed inclusive of residual ash. Acid Detergent Fibre (ADF) was expressed inclusive of residual ash. Acid Detergent Lignin (ADL) was determined by solubilisation of cellulose with sulphuric acid. Wet ash method was used to prepare samples to determine Ca (Atomic Absorption Spectrometry (AAS)), P (UV-Visible Spectroscopy) and K (Flame Emission Spectroscopy (FES)) contents. Leaf and stem biomass fractions varied significantly between the forage grasses. Leaf-to-stem ratio of *E. superba* was two times more compared to *E. macrostachyus* and *C. ciliaris.* Estimates of chemical components and derived estimates of energy values ADF, digestible dry matter (DDM), total digestible nutrients (TDN), metabolic energy (ME) and net energy of lactation (NE_l), maintenance (NE_m) and gain (NE_g) were significantly higher ($P > 0.05$) in leaf compared to stem biomass in all the grass species. Mineral content also varied between the leaf and biomass fractions with *E. superba* having significantly higher Ca content in leaf biomass fraction. Our results strongly suggest that *E. superba* is a more superior forage species compared to *E. macrostachyus* and *C. ciliaris*. In conclusion, *E. superba* demonstrated high potential for ruminant animal production. Therefore, considering its superior nutritive quality, wide ecological range and

adaptability to harsh climate, *E. superba* should be promoted for inclusion in pasture establishment programs in African dryland environments.

Key words: Tropical grasses; Biomass fractions; *Eragrostis superba*; *Enteropogon macrostachyus; Cenchrus ciliaris*

1. Introduction

In Africa, arid and semi-arid lands cover approximately 41% of the total land mass (Vohland and Barry, 2009). These dryland environments provide a rich source of forage to support different livestock production systems. Nomadic and transhumant systems characterised by mobility and flexibility to best utilise the patchy forage resources and unpredictable climatic conditions exemplify important livelihood strategies in African drylands. In Africa, pastoral communities inhabiting drylands derive most of their livelihoods from grazing livestock in natural pastures. Indigenous grasses such as *Cenchrus ciliaris* (African foxtail grass/Buffel grass), *Eragrostis superba* (Maasai love grass), *Enteropogon macrostachyus* (Bush rye grass) (Mganga et al., 2015), *Chloris roxburghiana* (Horsetail grass) (Mnene et al., 2005) and *Themeda triandra* (Red oat grass) (Snyman et al., 2013) constitute an important and reliable source of forage for free foraging livestock herds. This is mainly attributed to their adaptation to the harsh climatic conditions.

Furthermore, *C. ciliaris* is also known to have a high capacity to withstand heavy grazing, deep stabilising root system and responds quickly to rainfall events (Marshall et al., 2012). Herbage produced by *E. superba, E. macrostachyus* and *C. roxburghiana* is of good grazing value and palatable to cattle, sheep and goats (Mnene et al., 2005). *Themeda triandra* has often been described as a keystone grass forage species in Africa. This is attributed to its critical role in supporting grazing herbivores and thus vital to livestock production (Snyman et al., 2013). Despite their significant contribution to pastoral livelihoods, there is a dearth of information related to how these indigenous African grasses compare in allocating biomass to the leaf and stem fractions and the forage value of these individual biomass portions to ruminants.

Previous studies conducted in the last three decades to determine the chemical components (Abate et al., 1981; Kabuga and Darkoh, 1993; Koech et al., 2016) have aggregated leaf and stem biomass fractions. This approach conceals significant information related to the contribution of the separate biomass portions (Poorter et al., 2012) because: 1) biomass allocation to the leaf and stem fractions of terrestrial plants is not fixed and may vary over time, across environments and among species and 2) leaf-to-stem ratio play a significant role in ruminant diet selection and forage value determination. It is noteworthy that Stritzler et al. (1996) attempted to establish the chemical components of leaf and stem biomass fractions for semi-arid warm-season forage grass species in Argentina. However, the forage value of leaf and stem fractions were not compared statistically. Furthermore, Terry and Tilley (1964) using leaf and stem fractions of temperate grasses determined only the dry matter digestibility and not the chemical components. To our knowledge, studies to establish and compare biomass allocation to leaf and stem portions and chemical components of these separate fractions in indigenous grass species, especially those adapted to African dryland environments are absent.

Leaf and stem fractions of *E. superba, E. macrostachyus* and *C. ciliaris* were used to quantify biomass allocation, chemical and mineral components. These grasses were selected based on their contribution to livestock production in African drylands, evolved adaptive mechanisms for survival and multipurpose uses to the pastoral communities, notably as source of income (through the sale of seed and baled hay), thatching material (for houses and granaries) and soil conservation (Mganga et al., 2015). The objectives of this study were to determine and compare the (1) biomass allocation and (2) chemical and mineral components in the leaf and stem biomass fractions of the selected forage grasses. We hypothesise that (1) allocation of biomass in the leaf and stem fractions would be comparable in the three forage grass species and (2) chemical rather than mineral components in the leaf and stem fractions will be significantly different in the three grasses in their early vegetative phase.

2. Materials and methods

2.1. Forage biomass and fractionation

Forage yields (dry matter (DM) basis) of *E. superba, E. macrostachyus* and *C. ciliaris* were determined from fresh aboveground biomass. Quadrat sampling technique (Crocker and Tiver, 1948) was used to estimate biomass yields of the monoculture grass stands established in early November, 2017 at the South Eastern Kenya University research farm (1.31701, South 1◦ 19' 1.02317", 37.7543, East 37◦ 45' 26.75293" (own GPS data)), located in a typical semi-arid environment in Kenya. Basic site characteristics include; soil texture (6% sand, 31% silt, 22% clay), 0.08% Nitrogen, 0.8% Carbon and 165 mg kg^{-1} soil Phosphorus.

Briefly, fresh biomass of the grass species was clipped in their early vegetative phase at a stubble height of 2 cm within 0.25 m^2 size quadrat. Five (5) established pasture blocks measuring (20 X 60 m) were sampled. Each block was divided into three (3) separate subplots measuring (20 X 20 m) for each grass species. Biomass used for each grass species was obtained from 15 quadrats i.e. 3 quadrats per subplot for each species (n =15). Freshly harvested biomass was then placed in labelled brown paper bags and oven dried at 60º C for 48 h to estimate DM yields. Stem and leaf biomass were then carefully separated to determine the leaf-to-stem ratios. Thereafter, dried leaf and stem biomass for each quadrat was stored separately prior to chemical and mineral components analysis.

2.2. Forage laboratory analysis

Standard laboratory protocols were followed to establish the chemical components of the harvested forage. Dry Matter was estimated by oven drying at 60 °C for 24 h. Ash content was determined using the manual combustion in a muffle furnace at 650 °C for 24 h (Henken et al., 1986). Organic matter content was calculated as the difference between DM and Ash i.e. OM = DM - ash content. Nitrogen content (crude protein = N x 6.25) was determined by the conventional Kjeldahl method. Neutral Detergent Fibre (NDF) was assayed without heat stable amylase and expressed inclusive of residual ash (Mertens, 2002). Acid Detergent Fibre (ADF) was expressed inclusive of residual ash (Latimer, 2016). Acid Detergent Lignin (ADL) was determined by solubilisation of cellulose with sulphuric acid method (Robertson and Van Soest, 1981). Wet ash method was used to prepare samples to determine Ca (Atomic Absorption Spectrometry (AAS)), P (UV-Visible Spectroscopy) and K (Flame Emission Spectroscopy (FES)) (Pflaum and Howick, 1956) content. According to Khaled et al. (2002), the main chemical criteria that determine the forage value for ruminants are the concentration of NDF, ADL, CP, plant-digestible OM and minerals. Calcium, P and K were selected because they are the three most abundant mineral elements in livestock.

2.3. Statistics and data analyses

Statistical analyses were performed using Software STATISTICA 10.0, StatSoft Inc. One-way ANOVA was used to test for significant differences between the forage grasses. Fischer's LSD *post hoc* test was used to separate significant differences between treatments at $P<0.05$ significant level. All displayed results represent arithmetic means of 15 (leaf and stem biomass) replicates per species (n=15). Each replicate was derived from plant biomass in each sampled quadrat.

3. Results

Leaf and stem portions of total DM varied among the grasses. Significant differences were mainly observed in leaves. *Eragrostis superba* (2200 ±489 kg DM ha^{-1}) had significantly higher ($P <0.05$) leaf biomass compared to *C. ciliaris* (1167 ±263 kg DM ha^{-1}) and *E. macrostachyus* 1133 ±265 kg DM ha^{-1}) ranked second and third, respectively. However, stem biomass of *E. macrostachyus* (1500 ±151 kg DM ha^{-1}), *E. superba* (1400 ±228 kg DM ha^{-1}) and *C. ciliaris* (1367 ±248 kg DM ha^{-1}) were not significantly different ($P >0.05$) (Table 1). Leaf mass fraction of above ground biomass for *E. superba,* 0.61 was significantly higher ($P >0.05$) compared to those of *C. ciliaris* (0.46) and *E. macrostachyus* (0.43) ranked second and third, respectively. Leaf to stem ratio of *E. superba*, 1.57 was significantly different ($P <0.05$) and two times higher than those of *C. ciliaris* and *E. macrostachyus* with 0.85 and 0.76 respectively.

Chemical components content in both leaf and stem biomass varied though not significantly different ($P >0.05$) between the grass species (Tables 1 and 2). Dry matter (DM) and NDF content in leaf and stem biomass were not significantly different in the grasses. However, ash, OM, CP and ADL content showed significant differences ($P <0.05$) between the leaf and stem biomass in the grasses (Fig. 1). Digestible dry matter content (DDM), net energy of lactation (NE_l) and total digestible nutrients (TDN) were significantly higher (*P <0.05*) in leaf compared to stem biomass. Similarly, estimates of energy values ADF, digestible dry matter (DDM), total digestible nutrients (TDN), metabolic energy (ME) and net energy of lactation (NE_l), maintenance (NE_m) and gain (NE_g) were significantly higher (*P <0.05*) in leaf compared to stem biomass in all the grass species. (Table 1).

Mineral (Ca, P and K) content in leaf and stem biomass did not significantly differ (*P >0.05*) between the grass species (Tables 2 and 3). However, significant differences (*P <0.05*) were observed between the leaf and stem biomass but varied between the grasses. Calcium content was significantly different between the leaf and stem biomass only in *E. superba.* Phosphorus and Potassium content were significantly higher (*P <0.05*) in stem compared to leaf biomass in *E. macrostachyus.* Mineral (Ca, P and K) content in leaf and stem biomass was not significantly different (*P >0.05*) in *C. ciliaris* (Fig. 2).

4. Discussion

Leaf biomass fraction and leaf: stem ratio was higher in *E. superba* compared to *E. macrostachyus* and *C. ciliaris.* These results confirm that biomass allocation to different morphological components of terrestrial plants is not fixed and may vary among herbaceous species including grasses (Poorter et al., 2012). Ryser and Lambers (1995) also demonstrated that *Brachypodium pinnatum* allocated more of its above-ground biomass to the leaf fraction compared to *Dactylis glomerata* in a temperate nutrient-poor calcareous grassland. Ratio of leaf-to-stem biomass fractions in tropical forage grasses is of greater significance considering its contribution to diet selection, forage quality and intake by ruminants. Higher mean voluntary intake of leaf than stem biomass has been demonstrated in tropical grass forages *Chloris gayana, Digitaria decumbens, Panicum maximum, Pennisetum clandestinum* and *Setaria splendida*, associated with a shorter retention time of dry matter in the reticulo-rumen (Laredo and Minson, 1973). Relative proportions of the different morphological components (leaf blades and stems) have an essential role in controlling the chemical composition of tropical forage grasses. Considering the proportions of the leaf and stem fractions of the three grasses, it is envisaged that *E. superba* will demonstrate higher voluntary intake indices compared to *E. macrostachyus* and *C. ciliaris*.

Biomass allocation between the leaves and stems also has a significant influence on plant growth and development (Poorter and Negel, 2000). Leafy biomass is a strong driver of the capacity of plants to take up light and CO_2. High leaf biomass fraction and leaf: stem ratio in *E. superba* strongly suggest its competitive advantage over *E. macrostachyus* and *C. ciliaris* in capturing light for photosynthesis. Higher leaf fraction in *E. superba* strongly suggest its potential in C sequestration by capturing and reducing CO_2 levels in the atmosphere. Furthermore, higher leaf: stem ratio in *E. superba* demonstrate its adaptation to nutrient poor soils in dryland environments. According to Yan et al. (2011), plants adapted to nutrient limitation allocate less biomass into stems in arid-hot grasslands. Interestingly, the stem biomass fraction did not show significant differences among the three grasses. This suggests that under the prevailing environmental conditions, the grasses allocated a comparable amount of biomass to the stems to provide mechanical support and a hydraulic pathway. Understanding such patterns in biomass allocation is of fundamental importance to agricultural practice and implementation (Poorter et al., 2012).

Differences in the chemical components in the stem and leaf biomass fractions were not significant between the grass species. These findings conform to previous studies that showed no significant differences in the chemical components (e.g. CP, Ash, ADL, ADF and NDF) in the aggregated above-ground biomass of the same pasture species (Kabuga and Darkoh, 1993; Koech et al., 2016). Aggregate CP of 50 g/kg DM in all the three grasses analysed in this study demonstrate that they contain the required content for maintenance levels of CP for ruminants (50 g/kg DM) (Button et al., 1988) and therefore provide good source of forage for free grazing herbivores in dryland environments in Africa. Our findings compare well with those of Ramírez et al. (2004) who reported a CP content of 90 g/kg DM in *C. ciliaris* and introduced species in arid and semi-arid environments in Mexico. Similarly, aggregate CP content of the three grasses compared well with that of *Chloris gayana* (90 g/kg DM) commonly found in more humid climatic zones. However, these values are much less compared to the

CP content of other grasses notably *Pennisetum purpureum* (135 g/kg DM) and *P. maximum* (155 g/kg DM) also found in the tropics (Tan, 1970). However, *E. superba, E. macrostachyus* and *C. ciliaris* had significantly higher DM content (> 900 g/kg DM) compared to *C. gayana* (390 g/kg DM) (Abate et al., 1981). Low DM content in *C. gayana* is a characteristic of both mature and immature forages adapted to the humid climate compared to the three grasses adapted to the African dryland climate. Furthermore, the range of the chemical components Ash (40-90 g/kg DM), NDF (650-860 g/kg DM), ADF (400-590 g/kg DM) and ADL (50-190 g/kg DM) found in *C. ciliaris* and *E. superba* (Kabuga and Darkoh, 1993) compare well with those found in the leaf and stem biomass fractions of the selected grasses.

However, forage value in leafy biomass was significantly higher compared to stem biomass fractions in each of the grass species. Significant differences in the chemical components content between the leaf and stem biomass fractions are probably attributed to the metabolic role of the leaf and structural function of stems. Generally, leaf blades are more digestible, richer in CP and poorer in cell-wall constituents than stems, thus an increasing or decreasing forage value depend on the proportion of plant parts (Delagarde et al., 2000). Our results are consistent to other studies that have demonstrated leaf blades to have approximately twice as much CP as stems (Buxton, 1996). Neutral detergent fibre content, an estimate of the cell-wall concentration is negatively linked to digestibility and intake potential of forages. Leaf biomass fractions had low NDF concentration compared to stems. High digestibility of leaf compared to stem fractions has been established in temperate grass species (Terry and Tilley, 1964). Leafy biomass is usually retained in the rumen for a shorter period than stems because of faster rates of NDF digestion and higher rates of passage (Buxton, 1996). Grass forage species with higher leafy biomass are more nutritious and will be consumed and digested more readily compared to those with a larger stem biomass proportion.

Consequently, higher leaf: stem ratio in *E. superba* compared to *E. macrostachyus* and *C. ciliaris* demonstrate its greater potential value for livestock production. Pastoral communities in African drylands e.g. Pokot and Il Chamus in Kenya have identified *E. superba* as a key forage source for free ranging livestock. This is attributed mainly to its role in increased milk production and fattening

(Wasonga et al., 2003). Pastoral communities in Kenya practising reseeding to replenish depleted natural pastures have also demonstrated a higher preference to *E. superba* because of its high nutritional value for ruminants (Mganga et al., 2015). Pastoral Maasai of East Africa have observed that free grazing livestock have a tendency to select pasture patches dominated by *E. superba*. This observation conforms to previous studies that have shown leaf biomass fraction to be the best predictor of bite mass (BM) and instantaneous intake rate (IIR) across different phenological stages of a grasses (Baumont et al., 2000).

Similar to chemical component content, mineral (Ca, P and K) concentration did not differ significantly between the grasses. Mean concentration of Ca in *E. superba* (1.5 g/kg DM), *E. macrostachyus* (1.2 g/kg DM) and *C. ciliaris* (1 g/kg DM) was much less than 3 g/kg DM recommended for growing and mature cattle (Khalili et al., 1993). Calcium content of the grasses was also less compared to other tropical forage grasses *P. purpureum* (36 g/kg DM) and *P. maximum* (7.4 g/kg DM) reported in tropical Africa (Kambashi et al., 2014). Inadequate Ca content suggest that livestock grazing these pastures dominated by these grasses are likely to suffer Ca deficiency. Consequently, Ca supplementation e.g. mineral licks, is recommended when these grasses constitute the largest portion of the basal diet.

Phosphorus content range of 1.7-2.5 g/kg DM has been considered sufficient for grazing ruminants (Khalili et al., 1993). Generally, P concentration in all the selected grasses (5 g/kg DM) was much higher compared to those of *P. purpureum* (1.2 g/kg DM) and *P. maximum* (2.1 g/kg DM) (Kambashi et al., 2014). Critical percentage of phosphorus (2.5 g/kg DM) has been cited in *C. ciliaris* biomass established in a phosphate-deficient solodic soil (Andrew and Robins, 1970). Natural fertilisation through manure deposition by grazers contribute significantly to increased available P in open pastures in African drylands. This translates to high P in plant biomass. Higher P content than the critical range suggest that livestock can obtain sufficient P from the grasses thus not limiting production.

In addition to Ca and P, ruminants have a high K requirement to perform numerous body functions, growth and muscle development. Average K content of the analysed grasses was 5-6 g/kg DM. Ben-

Shahar and Coe (1992) reported 7.5 g/kg DM K content for *E. superba* in Kruger National Park, South Africa. Critical K levels for dairy cows (8 g/kg DM) and beef cattle, growing and fattening steers and heifers (6-8 g/kg DM) have been established (Reid and Horvath, 1980). Our results indicate that *E. superba, E. macrostachyus* and *C. ciliaris* are more suitable for the beef enterprise and growing and fattening of steers and heifers. Other tropical forage grasses with higher K content e.g. *P. purpureum* (33.6 g/kg DM) and *P. maximum* (23.8 g/kg DM) (Kambashi et al., 2014) are best suited for dairy production.

Plants allocate more nutrients to leaf biomass to support growth and only use nutrients stored in stems to satisfy the needs of leaves in limited conditions. However, Ca content was comparable in both biomass fractions for *E. macrostachyus* and *C. ciliaris*. Leaf and stem biomass fractions in *E. superba* and *C. ciliaris* also displayed comparable P and K contents. These results demonstrate a uniform distribution of the acquired nutrients to the more metabolic active tissues (i.e. leaves) and less active structural tissues (stems). This allocation pattern suggests that there was less demand for these nutrients in the leaf tissues during the early vegetative phase to trigger their translocation from the stem tissues. Furthermore, accumulation of nutrients in stem tissues indicate a possible strategy to store nutrients for a later moment, when the demand is intensified e.g. flowering and seed production. This probably explains higher P and K content in stem compared to leaf biomass fractions in *E. macrostachyus.* Unlike *E. macrostachyus* and *C. ciliaris, E. superba* demonstrated significantly higher Ca content in leaf compared to stem biomass fractions. Calcium delivery and allocation to biomass fractions is linked to transpiration rate. Lower transpiration rates result to lower Ca content of plant tissue (Gilliham et al. 2011). Accumulation of Ca in *E. superba* leaves suggest its higher transpiration rate compared to *E. macrostachyus* and *C. ciliaris*.

5. Conclusion

Indigenous grasses *E. superba, E. macrostachyus* and *C. ciliaris* are a key source of forage for free ranging livestock in African dryland environments. These forage species demonstrated different patterns of biomass allocation and forage quality in the leaf and stem fractions. *Eragrostis superba* allocated significantly more biomass to the leaf than the stem fraction, translating to two times higher leaf-to-stem ratio, compared to *E. macrostachyus* and *C. ciliaris.* Furthermore, forage value (chemical and mineral components) was largely higher in leaf compared to stem biomass fractions in all the selected grasses. These outcomes demonstrate that *E. superba* is a superior forage species compared to *E. macrostachyus* and *C. ciliaris*. These observed results relate well to indigenous technical knowledge among pastoral communities in African drylands who have identified *E. superba* to be an important forage species for pastoral livestock production systems.

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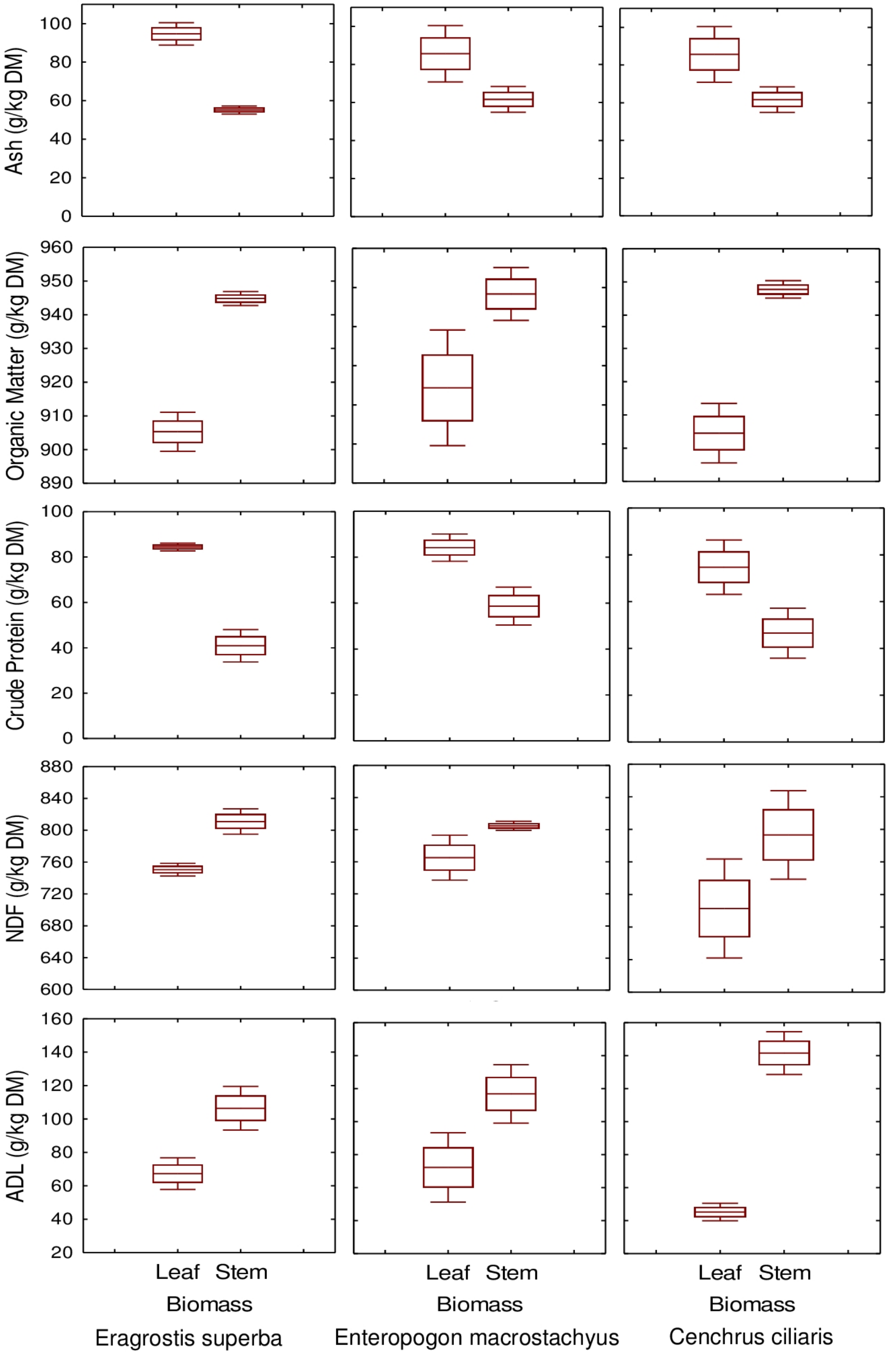

Fig. 1. Chemical components in leaf and stem biomass fractions of the selected grasses indigenous to dryland Africa. All displayed results represent arithmetic means of 15 (leaf and stem biomass) replicates per species (n=15).

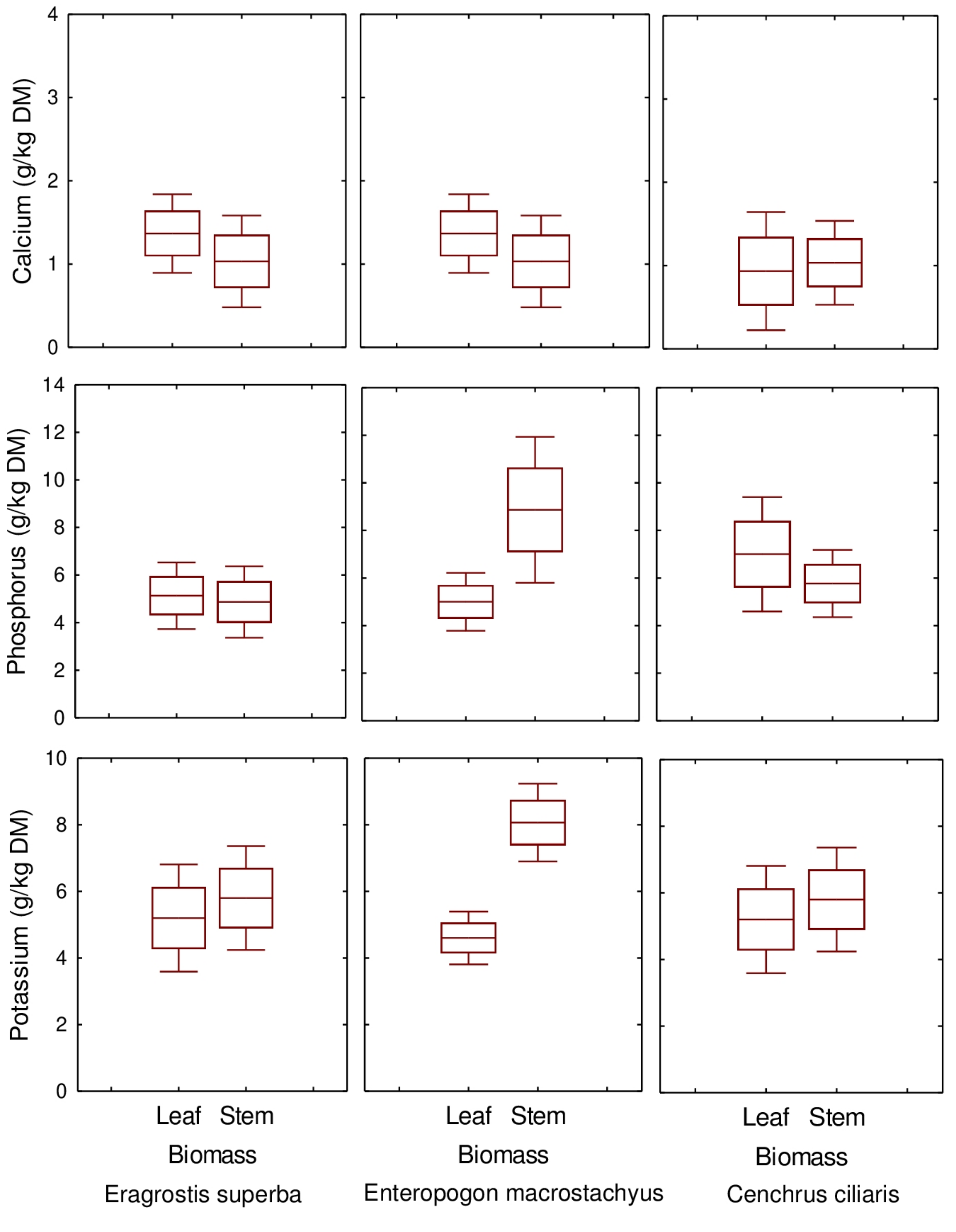

Fig. 2. Mineral content in leaf and stem biomass fractions of the selected grasses indigenous to dryland Africa. All displayed results represent arithmetic means of 15 (leaf and stem biomass) replicates per species (n=15).

Table 1 Plant biomass and estimates of energy values of three forage grasses from %ADF

Species	Part part	Biomass (kg $^{ha-1}$ DM)	ADF g/kg DM	DDM g/kg DM	TDN g/kg DM	ME	NE_l	NE_m	NE_g
							………….. Mcal/100 lb …………..		
ES	Leaf	2200a ±489	389a ± 4	586a ± 3	61.2a ± 2	1.01a ±0.01	56.1a ±0.5	61.4a ±0.4	35.2a ±0.4
	Stem	1400b ±228	524b ± 7	481b ± 6	52.4b ± 4	0.86b ±0.01	39.5b ±0.8	47.7b ±0.7	22.6b ±0.6
EM	Leaf	1133b ±265	391a ± 6	584a ± 4	61.1a ± 4	1.00a ±0.01	55.9a ±0.7	61.1a ±0.5	34.9a ±0.5
	Stem	1500b ±151	531b ± 13	475b ± 10	51.9b ± 9	0.85b ±0.01	38.6b ±1.6	46.9b±1.3	21.9b ±2.5
CC	Leaf	1167b ±263	365a ± 23	605a ± 18	62.8a ± 15	1.03a ±0.03	59.2a ±2.8	63.7a ±0.8	37.3a ±2.0
	Stem	1367b ±248	491b ± 12	507b ± 9	54.5b ± 8	0.90b ±0.01	43.5b ±1.4	51.1b ±1.2	25.8b ±1.1

where: ES – *Eragrostis superba*, EM – *Enteropogon macrostachyus,* CC – *Cenchrus ciliaris*

Means followed by different letters are significantly different at $P < 0.05$ as determined using Fisher's LSD Mean comparison test.

$\%DDM = 88.9 – (0.779 \times \%ADF)$

$\%TDN = 31.4 + (Ne_l \times 0.531)$

$NE_l = 104.4 – (1.24 \times \%ADF)$

$NE_m = (137 \times ME) – (30.42 \times ME^2) + (5.1 \times ME^3) – 50.8$

$NE_g = (142 \times ME) – (38.36 \times ME^2) + (5.93 \times ME^3) -74.84$

$ME = \%TDN \times 0.01642$

Table 2 Chemical component composition (g/kg DM) in leaf biomass

Species	DM	Ash	OM	CP	NDF	ADF	ADL	Ca	P	K
Eragrostis superba	950 ±1.5a	95 ±2.9a	905±5.8a	85±1.7a	751 ±4.0a	389 ±3.7a	67±4.7a	2.1 ±0.5a	5.1 ±0.7a	5.2 ±0.8a
Enteropogon macrostachyus	953 ±2.9a	86 ±7.3a	914±14.7a	84 ±5.9a	765 ±14a	391 ±5.5a	72 ±10.5a	1.4 ±0.2a	5.0 ±0.6a	4.6 ±0.4a
Cenchrus ciliaris	948 ±3.2a	95 ±4.4a	905±9.0a	75 ±11.5a	702 ±30.4a	365±22.7a	45 ±2.7a	0.9±0.04a	7.0 ± 1.2a	6.2 ±0.5a

DM – Dry Matter; OM – Organic Matter; CP – Crude Protein; NDF – Neutral Detergent Fibre; ADL – Acid Detergent Fibre; Ca – Calcium; P –Phosphorus; K – Potassium. Column means with different letters are significantly different at P < 0.05 as determined using Fisher's LSD Mean comparison test.

Table 3 Chemical component composition (g/kg DM) in stem biomass

Species	DM	Ash	OM	CP	NDF	ADF	ADL	Ca	P	K
Eragrostis superba	958 ±0.6a	55 ±1.0a	945 ±2.1a	41±7.1a	811 ±7.9a	524 ±6.6a	107±6.5a	0.7 ±0.2a	4.9 ±0.75a	5.8 ±0.8a
Enteropogon macrostachyus	951 ±5.6a	62 ±3.3a	938 ±6.7a	59 ±8.2a	805 ±2.8a	531 ±12.8a	117 ±8.8a	1.0 ±0.3a	8.8 ± 1.5a	8.1 ±0.6a
Cenchrus ciliaris	952 ±3.7a	52 ±1.3a	948 ±2.6a	47 ±10.7a	793 ±27a	491±11.5a	142 ±6.4a	1.0 ±0.3a	5.8 ±0.7a	4.3 ±0.5a

DM – Dry Matter; OM – Organic Matter; CP – Crude Protein; NDF – Neutral Detergent Fibre; ADL – Acid Detergent Fibre; Ca – Calcium; P –Phosphorus; K – Potassium. Column means with different letters are significantly different at P < 0.05 as determined using Fisher's LSD Mean comparison test.

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To
The Editor-in-Chief
Animal Feed Science and Technology

RE: Conflict of Interest Statement

The authors declare no conflict of interests.

Yours sincerely,

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